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PATENT

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Docket No. ____-CS

Sir:

Transmitted herewith for filing is the patent application of:

Inventor(s): MELANSON, John Laurence

For: CIRCUITS AND METHODS FOR REDUCING INTERFERENCE FROM SWITCHED MODE CIRCUITS

Enclosed are: 3 Sheets of Drawings

An assignment of the invention to:

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	Number		Number Extra	Rate	Basic Fee $ 690.00
Total Claims	25	- 20 =	5	x $18=	$ 90.00
Independent Claims:	4	- 3 =	1	x $78=	$ 78.00
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Date August 30, 2000

James J. Murphy
James J. Murphy
Attorney for Applicant
Registration No. 34,503

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PATENT APPLICATION
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S. Taylor Lenz

Signed ______August 30, 2000

CIRCUITS AND METHODS FOR REDUCING INTERFERENCE
FROM SWITCHED MODE CIRCUITS

MELANSON, John Laurence
2001 South Mopac, No. 2001
Austin, Travis County,
Texas, 78746

Citizen: United States of America

::ODMA\PCDOCS\DALLAS_1\3353144\1
233:2836-P108US

CIRCUITS AND METHODS FOR REDUCING INTERFERENCE FROM SWITCHED MODE CIRCUITS

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates in general to switched mode electronic circuits and in particular to circuits and methods for reducing interference from switched mode circuits.

DESCRIPTION OF THE RELATED ART

Class D audio power amplifiers (APAs) have been used for many years in systems, such wireline telephony, where high bandwidth is not critical. More recently however, new fabrication techniques, and in particular, new techniques for fabricating power transistors, have made integrated Class D APAs possible. This has extended their potential applications to lower-power, higher-bandwidth systems, including battery-powered portable music players and wireless communications devices.

One major advantage of Class D amplifiers is their efficiency. Generally, an audio signal is converted into a relatively high frequency stream of pulses varying in width with the amplitude of the audio signal. This pulse width modulated (PWM) signal is used to switch a set of power output transistors between cutoff and saturation which results in efficiencies above 90%. In contrast, the typical Class AB push-pull amplifier, using output transistors whose

conduction varies linearly during each half-cycle, has an efficiency of around %60. The increased efficiency of Class D amplifiers in turn reduces power consumption and consequently lowers heat dissipation and improves battery life.

Similarly, switched mode power supplies have found wide acceptance in the design of compact electronic appliances. Among other things, switched mode power supplies advantageously use smaller transformers and are therefore typically more compact and lighter weight. This is in addition to the increased efficiency realized over linear power supplies. Moreover, the total number of components can be reduced to, for example, a power MOSFET die and a PWM controller die packaged together in a single package.

Given the importance of improved battery-life, reduced heat dissipation, and component size minimization in the design and construction of portable electronic appliances, improved switched mode techniques will have numerous practical advantages. The possible applications for these techniques are numerous, although Class D APAs and switched mode power supplies are two primary areas which should be considered.

SUMMARY OF THE INVENTION

According to the principles of the present invention, a system is disclosed which includes a radio receiver and switched mode circuitry operating at a selected switching frequency. Circuitry is included for setting the switching frequency of the switched mode circuitry 114/115 as a

function of a frequency of a signal being received by the radio receiver.

The inventive concepts address one of the major disadvantages of conventional switched mode devices, namely, interference (noise) caused by the switching mechanism itself. This interference is of particular concern in systems employing radio receivers and similar interference sensitive circuitry. In accordance with the inventive principles, the switching frequency is shifted as a function of the radio frequency being received such that the switching frequency and its harmonics fall outside the frequency band of the received signal. Advantageously, these principles can be applied to different types of switched circuitry, including pulse width modulated power supplies and class D amplifiers.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a diagram of one channel of a digital radio embodying the principles of the present invention;

FIGURE 2 is a diagram of a Class D pulse width modulated (PWM) amplifier suitable for use as audio power amplifier in the system of FIGURE 1;

FIGURE 3 is a diagram of a switched mode power supply for purposes of illustrating the inventive concepts.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The principles of the present invention and their advantages are best understood by referring to the illustrated embodiment depicted in FIGURES 1-3 of the drawings, in which like numbers designate like parts.

Figure 1 is a functional block diagram of one channel of a digital radio 100 embodying the principles of the present invention. Digital radio 100 includes an analog section or front-end 101 which receives radio frequency (RF) signals from an associated antenna 102. Analog front-end 101 is preferably a conventional RF down-converter including a low noise amplifier (LNA) 103 for setting the system noise figure, a bandpass filter 104 and mixer 105 driven by an analog local oscillator 106. The mixed-down analog signal is then converted into digital form by analog to digital converter 107.

The digitized data output from A / D converter 107 is passed to digital processing section 108. A pair of mixers 109a,b generate in-phase (I) and quadrature (Q) signals from a corresponding pair of clock phases from crystal oscillator 110. The I and Q signals are next passed through bandpass filters 111a and 111b and on to digital baseband processor 112. The processed digital signal is then re-converted to analog (audio) form by D/A converter 113.

According to the principles of the present invention, a switched mode (Class D) audio power amplifier (APA) 114, discussed in detail below, is used to drive an external set of speakers or a headset. Preferably, at least some of the components of digital radio 100 are powered by a switched

mode power supply (SMPS) 114. Power supply 114 will also be discussed further below.

One of the disadvantages of using conventional switched mode devices is the interference (radiated and conducted) generated by the switching mechanism. This problem is of particular concern in compact electronic appliances which include a radio and similar audio circuits. For example, if the switching frequency is nominally at 350 kHz, harmonics will be generated at 700 kHz, 1050 kHz and 1400 kHz, all of which fall within the AM broadcast band. In order to insure that these signals do not interfere with radio reception, as well as preventing injection of noise into the system at other points, shielding and circuit isolation could be used. However, these alternatives are not practical in low cost and/or compact electronic appliances.

According to the inventive concepts, if radio 100 is receiving a signal near one of the harmonics of the switching frequency, the switching frequency is moved such that the resulting switching noise will not interfere with received signal. Assume that two possible switching signals A and B, used in either APA 114 or SMPS 115, or both, have base frequencies of 350 kHz and 380 kHz, respectively. (More than two signals can be used to provide a greater resolution). The corresponding harmonics are then:

A (kHz)	B (kHz)
700	760
1050	1140

1400	1520

One of the signals A and B is then selected as a function of the frequency of the received signal. In this example, where an AM radio is being assumed, the selection could be made as follows:

Receive Freq. (kHz)	Switching Signal
Under 730	B
930 -910	A
910 - 1100	B
1110 - 1280	A
1290 - 1460	B
Above 1460	A

As a result, the interference created by the switching signal and its harmonics are moved above or below the reception band, where their effect on noise performance is minimized.

In a digitally controlled system, the selection of the reception band is performed by a microcontroller or microprocessor which can accordingly also instruct the PWM control circuitry to change frequency. In the case of an analog oscillator, the PWM control circuitry can count the frequency of the local oscillator and choose the PWM frequency accordingly. The different switching frequencies

can be generated using either an oscillator with multiple crystals or by frequency division.

FIGURE 2 is a simplified functional block diagram of a Class D pulse width modulated (PWM) amplifier 200 suitable for use as APA 114 in one channel of system 100. It should be noted that a while a basic full-bridge amplifier is shown, other circuit designs may be used to practice the inventive concepts, including half-bridge Class D amplifiers.

In the full-bridge approach, four power MOSFETs 201a,d are used to drive the differential output from a single voltage supply Vdd under the control of gates and drivers 202a,b. In this embodiment, only one transistor of the upper transistor pair and one transistor of the lower transistor pair of MOSFETs is on and conducting in saturation while the other MOSFET in each pair is completely turned-off.

The gates/drivers 202a,b are controlled by a PWM modulated signal generated by digital PWM controller 204 which receives the analog audio signal Audio In, along with a high speed clock and a lower frequency clock, discussed below. PWM controller 204 also receives feedback from the outputs of the MOSFET pairs. PWM signal generation techniques are discussed in coassigned U.S. Patent No. 5,815,102 to *Melanson,* entitled "Delta Sigma PWM DAC to Reduce Switching" and incorporated herein by reference. The result is a PWM signal having pulse widths proportional to the input signal amplitude. At the output, a low pass

filter 203 is used to recover the amplified audio input signal.

According to the present inventive concepts, the frequency of low frequency clock (square wave) can be adjusted, as described above, such that the PWM switching signal driving the output MOSFETs (through gates /drivers 202) is shifted out of the reception band.

The inventive concepts provide at least two ways to generate a variable frequency square wave. (The options are generally indicated in the figures by dashed lines.) According to one embodiment, a crystal oscillator 206 selectively operates from one of a plurality of crystals 207 of differing resonance frequencies. A microcontroller 208, selects the crystal, and therefore the frequency, as a function of the selected receive frequency or frequency band. As indicated above, in a digital controlled radio, the receive frequency is known from the tuner selection and in an analog system from counting the LO. The primary advantage with this embodiment is that all the divide ratios remain the same.

According to the second embodiment, a programmable frequency divider 209 is used to generate multiple clock frequencies for driving ramp generator 205. Divider 209 could for example start with a base frequency of 512 fs, where fs is the sampling frequency used in the A/D conversion process, and divide by 64 to obtain a frequency of 8 fs. The resulting 64 time slots make it possible to generate PWM pulse widths from 0 to 64 periods wide. Similar, if the divide ratio is changed, for example, to 72,

then 72 time slots are available modifying the switching frequency in the ratio of 8:9. Preferably, divider 209 is programmable with the divide ratio selected by microcontroller 208 as a function of the received frequency.

These concepts can also be applied to switched mode power supplies, such as SMPS 115 in system 100. A simplified functional diagram of a switched mode power supply 300 is shown in FIGURE 3 for purposes of illustrating the inventive concepts. It should be noted that while the illustrated embodiment employs an analog ramp generator and analog comparator, that a digital PWM controller similar to that discussed above can also be instead used in SMPS 115.

SMPS 300 is based on a power MOSFET or semiconductor switch 301 driving an inductor 302 and output impedance 303. Inductor (core) 302 generally filters current ripple while a capacitor 304 is included for filtering voltage ripple. Free-wheeling diode 305 ensures that current is always flowing into inductor 302. A feedback loop is represented by differential error amplifier 306 which compares a feedback signal from the circuit output against a reference voltage Vref.

The output from error amplifier 306 is passed to the non-inverting input of modulator 307, the inverting input of which receives a triangle or sawtooth wave from ramp generator 308. As discussed above, the frequency of the square wave input into ramp generator 308 is varied depending on the frequency band of the received signal. Consequently, SWPS 300 also includes a crystal oscillator 309 controlled by a microcontroller 310. As indicated

above, the inventive principles provide at least two ways in which the switching frequency can be changed. In one option, a plurality of crystals 311 of different resonance frequencies are provided, in which case all the divide ratios remain the same. In the second option, a programmable frequency divider 312 is used to generate multiple frequencies by dividing down a base frequency, as described above.

Although the invention has been described with reference to a specific embodiments, these descriptions are not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as alternative embodiments of the invention will become apparent to persons skilled in the art upon reference to the description of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

It is therefore, contemplated that the claims will cover any such modifications or embodiments that fall within the true scope of the invention.

WHAT IS CLAIMED:

1. A system comprising:

a radio receiver;

switched mode circuitry operating at a selected switching frequency; and

circuitry for setting said switching frequency of said switched mode circuitry as a function of a frequency of a signal being received by said radio receiver.

2. The system of Claim 1 wherein said switched mode circuitry comprises a switching power supply.

3. The system of Claim 1 wherein said switched mode circuitry comprises a Class D amplifier.

4. The system of Claim 1 wherein said circuitry for setting said switching frequency of said switched mode circuitry comprises:

a plurality of crystals of differing resonance frequencies;

a crystal oscillator for generating said switching frequency from a selected one of said crystals; and

control circuitry for selecting said selected one of said crystals.

5. The system of Claim 1 wherein said circuitry for setting said switching frequency of said switched mode circuitry comprises:

a signal generator for generating a base frequency;

a programmable divider for dividing said base frequency by a selected divisor to generate said switching frequency;

control circuitry for selecting said divisor.

6. The system of Claim 1 wherein said circuitry for setting said switching frequency includes a microcontroller operable to select said switching frequency in response to selection of a reception frequency band by user input.

7. The system of Claim 1 wherein said circuitry for setting said switching frequency detects said frequency of said signal received by said radio receiver by measuring a local oscillator frequency.

8. The system of Claim 1 wherein said switching frequency is selected such that at least one harmonic of said switching frequency lies outside a frequency band including said signal being received by said radio receiver.

12. The amplifier of Claim 9 wherein said pulse width modulation circuitry comprises:

a signal generator for generating a base signal of a selected base frequency;

a divider for dividing said base frequency by a selected divisor to generate a signal at said frequency of said pulse width modulated signal;

a microcontroller for selecting said divisor as a function of said frequency of said signal received by said radio receiver; and

circuitry for converting said signal at said frequency of said pulse width modulated signal into said pulse width modulated signal.

13. The amplifier of Claim 12 wherein said signal generator comprises a crystal oscillator.

14. The amplifier of Claim 9 wherein said output transistor comprises a metal oxide semiconductor field effect transistor.

15. The amplifier of Claim 9 wherein said frequency of said pulse width modulated signal is selected such that at least one harmonic of said pulse width modulated signal is outside a selected frequency band including said signal received by said radio receiver.

16. A switched mode power supply for use in a system including a radio receiver comprising:
a transistor for driving an output; and
circuitry for generating a pulse width modulated signal for switching said transistor on and off at a switching frequency selected as a function of a reception frequency of said radio receiver.

17. The power supply of Claim 16 wherein said switching frequency is selected such that at least one harmonic of said switching frequency is outside a selected frequency band including said signal received by said radio receiver.

18. The power supply of Claim 16 wherein said circuitry for generating comprises:
a crystal oscillator for generating said switching frequency using a selected one of a plurality of crystals of differing resonance frequencies; and
circuitry for selecting the one of the plurality of crystals for generating said switching frequency as a function of a frequency of said reception frequency.

19. The power supply of Claim 18 wherein said circuitry for selecting comprises a microcontroller.

20. The power supply of Claim 16 wherein said circuitry for generating comprises:

a base frequency generator; and

a programmable divider for dividing said base frequency by a selected divisor to generate said switching frequency.

21. A method of switching a power transistor used in a radio receiver comprising the steps of:

determining a frequency of a received signal being received by the radio receiver; and

generating a switching signal for switching the power transistor in response to said step of determining, a frequency of the switching signal selected such that at least one harmonic of the switching signal is outside a frequency band including the frequency of the received signal.

22. The method of Claim 21 wherein the radio includes a local oscillator and said step of determining comprises the step of counting periods of the local oscillator.

23. The method of Claim 21 wherein the radio includes a microcontroller and said step of determining comprises the step of decoding user input selecting the frequency of the received signal.

24. The method of Claim 21 wherein said step of generating comprises the substeps of:

selecting a crystal from a plurality of crystals of differing resonance frequencies; and

generating the frequency of the switching signal from the selected crystal using a crystal oscillator.

25. The method of Claim 21 wherein said step of generating comprises the substeps of:

generating a base frequency; and

dividing the base frequency by a selected factor to generate the switching frequency.

CIRCUITS AND METHODS FOR REDUCING INTERFERENCE FROM SWITCHED MODE CIRCUITS

ABSTRACT OF THE DISCLOSURE

A system 100 including a radio receiver 101/ 108 and switched mode circuitry 114/115 operating at a selected switching frequency is disclosed. Circuitry 207-209 sets the switching circuitry of the switched mode circuitry 114/115 as a function of a frequency of a signal being received by a radio receiver 101/108.

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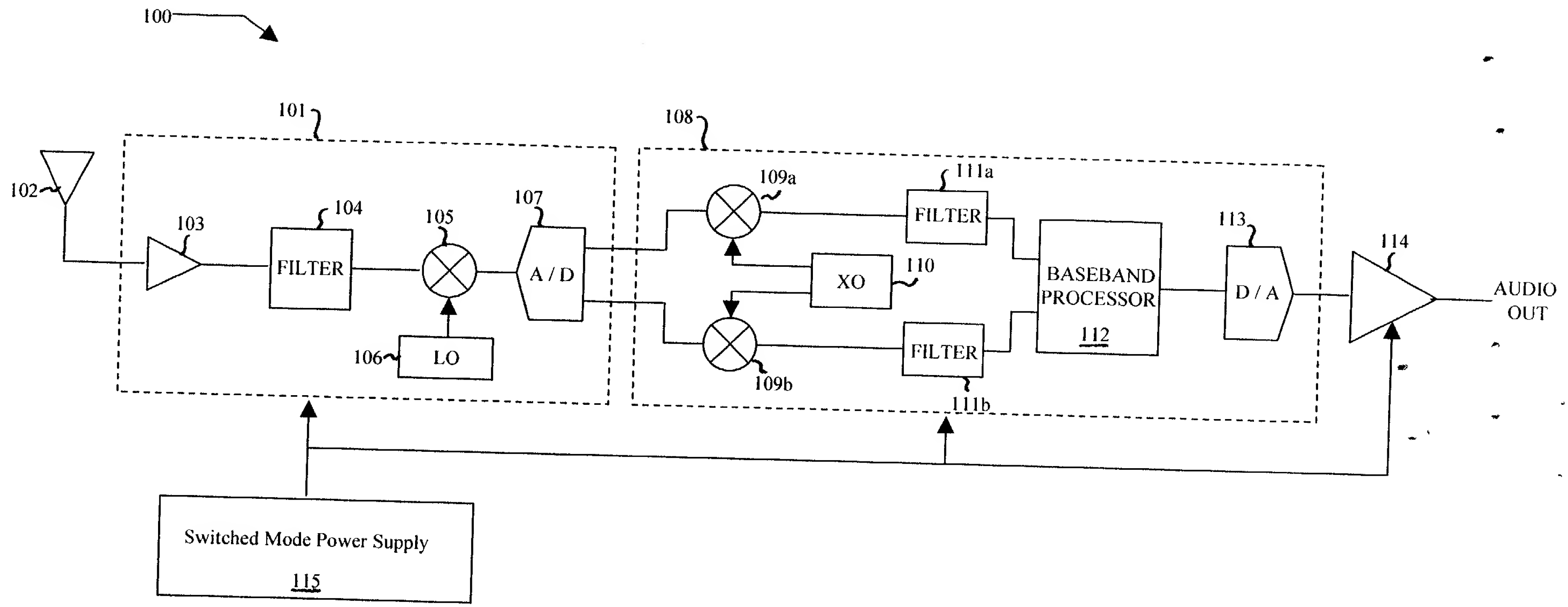
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108
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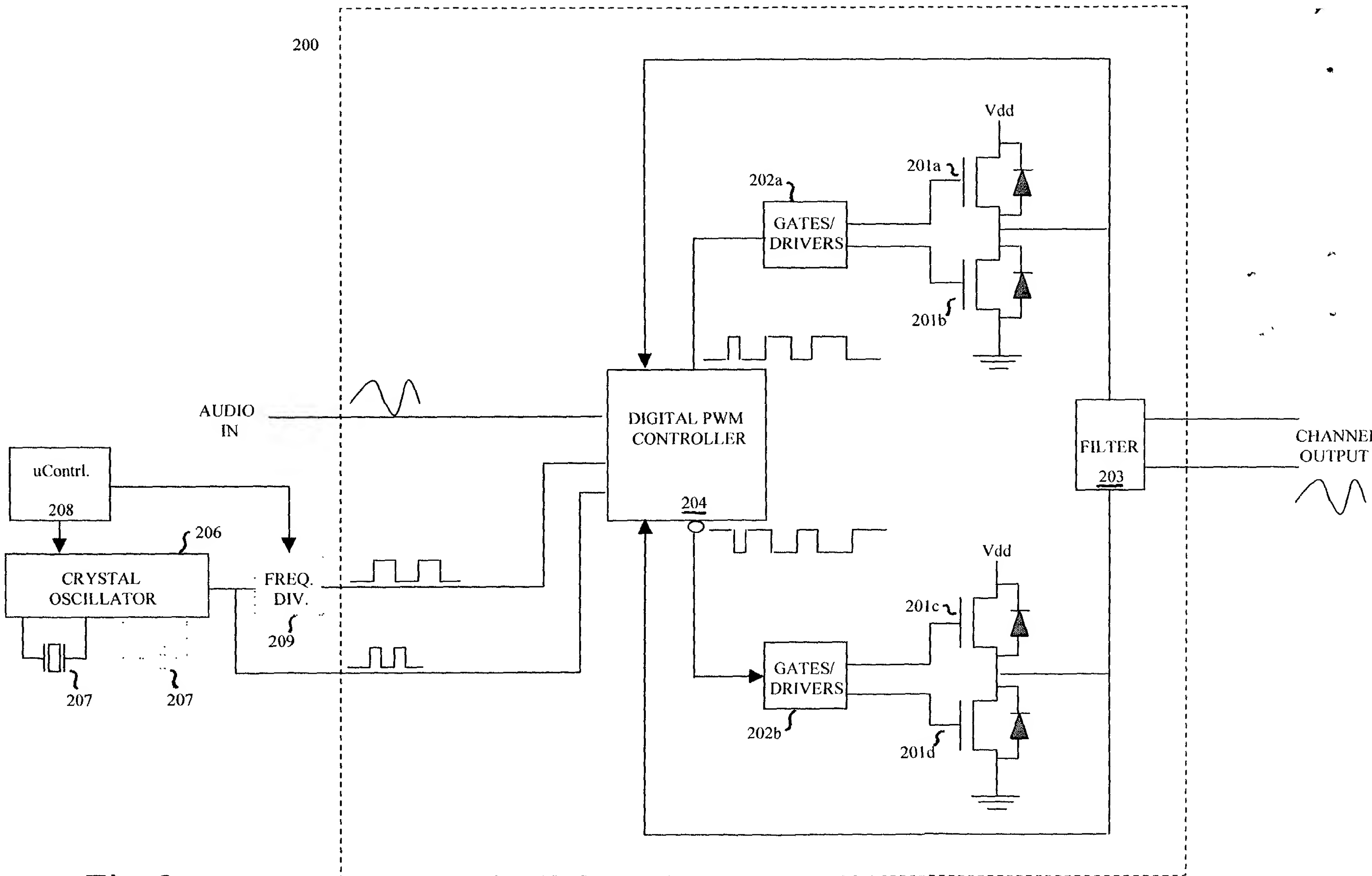
BASEBAND
PROCESSOR
112
D / A
113
114
AUDIO
OUT
Switched Mode Power Supply
115

Fig. 1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AUDIO IN
DIGITAL PWM CONTROLLER
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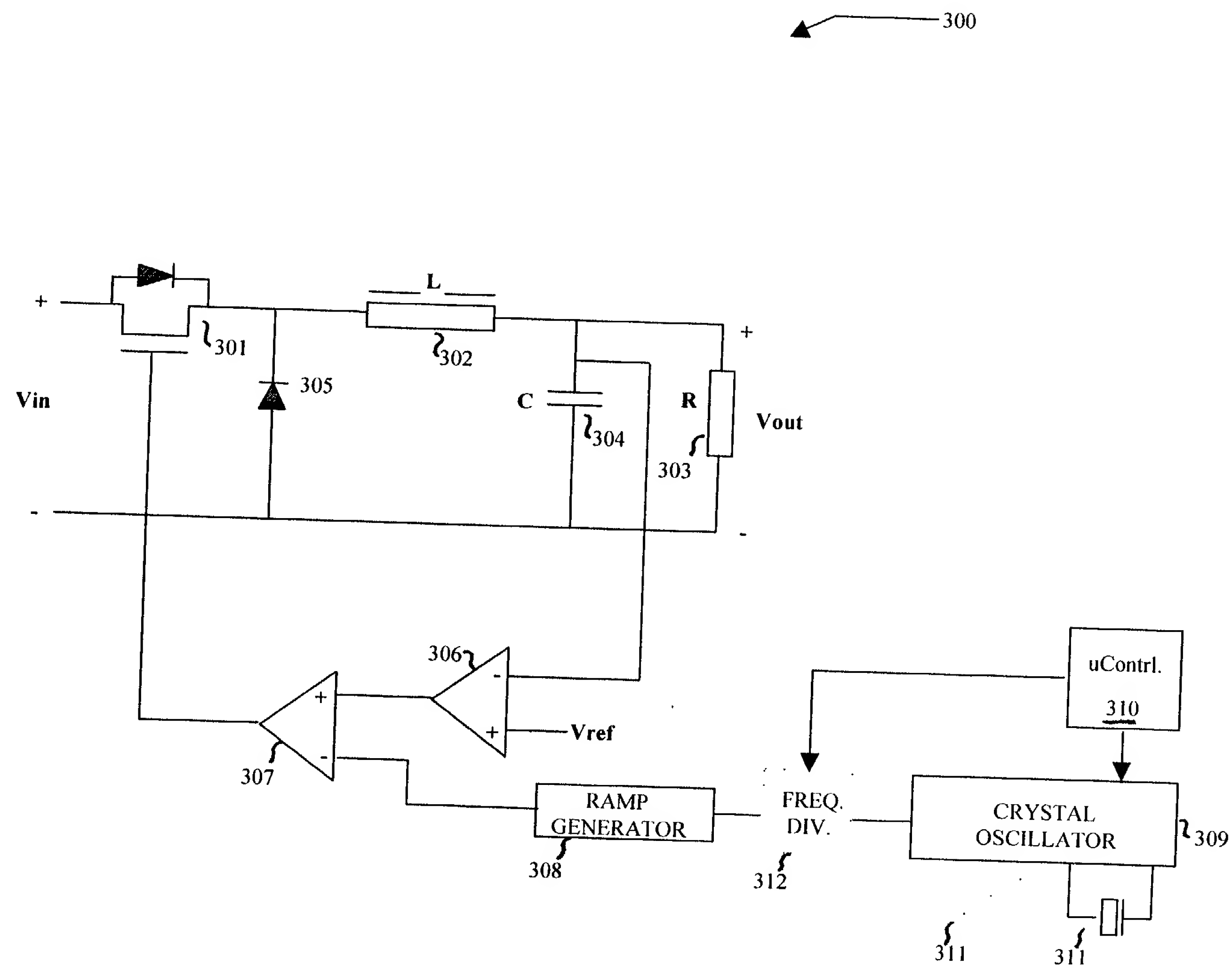
GATES/ DRIVERS
202a
GATES/ DRIVERS
202b
Vdd
201a
201b
Vdd
201c
201d
FILTER
203
CHANNEL OUTPUT

Fig. 2

Fig. 3



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uContrl.
310
CRYSTAL OSCILLATOR
309
311
311

PATENT APPLICATION
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DECLARATION AND POWER OF ATTORNEY
Original Application

As below named inventor, I declare that I have reviewed and understand the contents of the specification, including the claims, as amended by any amendment specifically referred to in this Declaration, that the information given herein is true, that I believe that I am the original, first and joint inventor of the invention entitled:

CIRCUITS AND METHODS FOR REDUCING INTERFERENCE FROM SWITCHED MODE CIRCUITS

which is described and claimed in:
XX_ the attached specification or
___ the specification in application Serial No. ______ filed ______
that I acknowledge my duty to disclose information in accordance with 37 C.F.R. Section 1.56 and defined on the attached sheet, which is material to the examination of this application, that I do not know and do not believe the same was ever known or used in the United States of America before my or our invention thereof or patented or described in any printed publication in any country before my or our invention thereof, or more than one year prior to this application, that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns more than twelve months prior to this application and that as to applications for patent or inventor's certificate filed by me or my legal representatives or assigns in any country foreign to the United States of America, the earliest filed foreign application(s) filed within twelve months prior to the filing date of this application and all foreign applications filed more than twelve months prior to the filing date of this application, if any, are identified below.

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__ Required information as to foreign applications filed prior to the filing date of this application is on page __ attached hereto and made a part hereof.

POWER OF ATTORNEY:
As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

NAME	REGISTRATION NO.
Peter Rutkowski	32,627
J.P. Violette	33,042
Dan A. Shifrin	34,473
James J. Murphy	34,503
Ehrlich, Henry L.	39,663
Garsson, Ross S.	38,150
Kordzik, Kelly K.	36,571
Mason, Dwayne	38,959
Newberger, Barry	41,527
Rogers, Charles J.	38,286
Schwartz, Rocky	27,227
Shaddox, Robert C.	34,011

SEND CORRESPONDENCE TO:
WINSTEAD SECHREST & MINICK
P. O. Box 50784
1201 Elm
Dallas, Texas 75270

DIRECT TELEPHONE CALLS TO:

James J. Murphy, Esq.
(214) 745-5374
Fax: (214) 745-5374

Winstead Sechrest & Minick, P.C.'s customer number is 23-2426.

(201) FULL NAME OF INVENTOR	LAST NAME MELANSON	FIRST NAME John	MIDDLE NAME Laurence	
RESIDENCE & CITIZENSHIP	CITY Austin	STATE OR FOREIGN COUNTRY Texas	COUNTRY OF CITIZENSHIP United States of America	
POST OFFICE ADDRESS	POST OFFICE ADDRESS 2001 South Mopac, Apt. 2001	CITY Austin	STATE OR COUNTRY Texas, USA	ZIP CODE 78746

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

PATENT APPLICATION
File Number: ____-PC

Name (201)	Signature	Date
MELANSON, John		

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Section 1.56 Duty to Disclose Information Material to Patentability

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by Sections 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applications to carefully examine:

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record of being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the application takes in:

(i) opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of patentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any considerations given to

evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

© Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent or inventor.

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